Electrostatic Discharge in Rotating Machinery

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Some rotating machines, because of electrical or mechanical characteristics, induce an electrical potential (voltage) on their rotating shafts. If this voltage is not managed, or if the voltage mitigation system (often a shaft-grounding brush) is not maintained and fails, the voltage seeks an alternate path to ground. That path is the metal component – typically a bearing or seal – closest to the shaft, and electric arcing to that component is termed electrostatic discharge. Arcing erodes metal surfaces and opens the tight clearances that these components depend upon for proper operation. If undetected, electrostatic discharge will gradually destroy the bearing or seal, change the rotor dynamics of the machine, and may ultimately result in damage to the shaft that requires expensive rework. Properly maintaining and inspecting the voltage mitigation system and monitoring the rotor dynamics of the machine with a Bently Nevada machinery protection or management system can help to avoid this problem.

Fluid-Film Bearing Machines

In an operating steam turbine generator (STG), there are at least three possible sources of voltage between the shaft and ground:

1. Electromagnetic loop voltage due to asymmetries in the generator magnetic paths may create an electric potential between opposite ends of the generator shaft.
2. Static charges may build up from droplets of water being thrown off blades in wet stages of the turbine.
3. A capacitive voltage due to a ripple on the DC field voltage may result in a voltage from shaft to ground.

Manufacturers take these voltages into account when they design their machines. The bearing at one end of a generator is normally insulated to create an open circuit and prevent electromagnetic loop voltage. Voltages between the shaft and ground, due to a static charge or DC voltage ripple, can be mitigated by the installation of grounding brushes that ride on the shaft near the uninsulated generator bearing. The brushes keep the shaft-to-ground voltage at a safe level by bleeding off current and causing the weak source voltage to decay. [Editor's Note: When instrumentation is installed in insulated bearings, special care must be taken to ensure the insulating properties are maintained. See our article, *Installing Instrumentation on Insulated Bearings*, on page 19 for additional information.]

Rolling Element Bearing Machines

Industry observers suspect that similar mechanisms are behind a rise in rolling-element bearing failures in motors controlled by adjustable-speed drives [1]. These drives simulate three-phase power by creating a series of voltage pulses that only approximate the smooth sinusoidal waveform of each phase. Since the roughness of the "pulse width modulated" waveform prevents them from adding vectorially to zero at every given instant, a "common mode voltage" relative to ground is created. This common mode voltage can generate bearing currents in at least three possible ways:

1. The air gap between rotor and stator acts like a capacitor that periodically discharges when bearing components contact. This is believed to be the major cause of bearing damage.
2. Another phenomenon causes current to flow when the effective bearing impedance is very low, and the bearings become the path to ground for parasitic winding capacitances.
3. An inductive effect causes a current to circulate through the bearings, shaft, and stator enclosure when the impedance of this circuit is low.

Mitigation techniques for these situations either block bearing currents or provide a low-impedance path to ground. These techniques include shaft grounding brushes,

bearing insulation, ceramic rolling elements or conductive grease, a Faraday shield, and dual-bridge inverters that balance the excitation of the motor.

Failure Mechanisms

Occasionally, insulation or grounding brushes wear out or become ineffective, resulting in a large current flow through the bearings. In fluid-film bearings, this can lead to electrostatic discharge through the oil film that melts a minute area of the Babbitt metal. Continued discharges over a period of time can lead to pitting erosion, visible as a frosted appearance of the bearing surface, and ultimately a wiped bearing. If the problem goes undetected long enough, the shaft surface at the bearing may become pitted to the extent that surface repair is required. This results in a significant machine outage to remove and repair the shaft. In some cases, the shaft also requires degaussing to remove a high level of residual magnetism.

A similar pitting occurs in rolling element bearings. In the early stages, the bearing race exhibits an evenly distributed satiny finish. In advanced stages, evenly spaced deep flutings appear on the outer bearing race. The fluting is especially distinct when the motor runs at a constant speed.

Detection

In fluid-film bearings, electrostatic discharge results in erosion of the bearing and is observable by changes in the bearing clearance. This can be monitored via the probe gap voltages; as the bearing clearance opens, gap voltage will change. Therefore, the following are recommended practices for monitoring:

- Enable gap alarming on your Bently Nevada monitoring system. This is available on 3300/16 and 3300/61 monitors as well as 3500 monitors.
- Regularly review shaft centerline plots using software such as Data Manager® 2000.
- Trend gap readings using software such as Data Manager® 2000.

The article *The Importance of Shaft Centerline Position* on page 26 of the June 1995 ORBIT provides additional information about trending gap voltage and using average shaft centerline plots.

Some machines have Original Equipment Manufacturer (OEM)-provided voltage- and current-measuring instrumentation in the grounding brush circuits that will alarm on a high level of either parameter. Both the voltage mitigation systems and their associated instrumentation should be checked regularly.

For rolling element bearings, seismic or REBAM® transducers can be used to trend bearing vibration levels. In the advanced stages of pitting on the outer race, higher vibration levels can be detected.

Conclusion

Electrostatic discharge causes bearing and machine damage when electrical currents pass through bearing areas on their way from shaft to ground, or as they circulate through rotating and stationary components. Electrostatic discharge often goes undiagnosed because of its subtle symptoms, gradual effects, and because it is an electrical phenomenon that manifests itself as mechanical damage. Even non-electrical machines, such as turbines and gearboxes, are susceptible. (Editor's Note: For a case history on ESD on a compressor train, see the article on page 25 in this issue of ORBIT.) Although proper maintenance of brushes and insulators is the first line of defense, the effects of electrostatic discharge can be detected by a properly configured Bently Nevada protection system, and diagnosed by a properly optimized Bently Nevada machinery management system.

Reference:

1. Sharke, P., "Current Jam," *Mechanical Engineering*, Vol.122 No.5, May 2000, The American Society of Mechanical Engineers.